USER FACILITIES

CHAPTER 2

The research activities described in the previous chapter of this annual report are supported by the extensive facilities of the National High Magnetic Field Laboratory. Each of the consortium partners—Florida State University (FSU), the University of Florida (UF), and Los Alamos National Laboratory (LANL)—offers outstanding resources for users, but collectively, the three sites offer members of the worldwide science and engineering communities unprecedented opportunities to explore science at the extremes of magnetic field, pressure, and temperature.

The main facilities of the laboratory are located at FSU in Tallahassee in a modern, 330,000 sq. ft. complex dedicated to magnet-related research and technology. Housed at this site are superconducting, resistive, hybrid, and specialty magnets, along with the Magnet Science and Technology Group, the Center for Interdisciplinary Magnetic Resonance (CIMAR), and the Research Program. The NHMFL Pulsed Field Facility is located at LANL in New Mexico; and the Ultra-High B/T (magnetic field/temperature) Facility and the magnetic resonance imaging/spectroscopy (MRI/S) assets of the laboratory are located at UF in Gainesville. In addition to the "hardware" assets of the laboratory (presented in the following table), the close proximity of visiting users to the distinguished NHMFL faculty and the affiliated faculty at the three institutions sets the stage for very productive collaborations and cross-disciplinary scientific exchanges.

Table 1. NHMFL magnet systems.

SUPERCONDUCTING MAGNETS

FIELD (T), BORE (mm)	TEMPERATURE	SUPPORTED RESEARCH
20, 52* 19.5, 52* 15, 45* 15, 150* (30 x 70 mm split) 6, 100*	20 mK - 2 K 0.4 - 300 K 10 mK - 1 K 4.2 K 300 K	Magneto-optics—ultra-violet through far infrared Magnetization Specific heat Transport High pressure NMR in highest fields—low to medium resolution Mechanical stress testing
20, 52**	20 mK to 500 K	Magneto-optics—ultra-violet through near infrared Magnetization Mechanical properties Thermal expansion Specific heat Transport High pressure NMR in highest fields—low to medium resolution
20, 30***	0.5 mK	Quantum Hall effect Transport measurements in dilute ^{3}He-^{4}He mixtures Order phases in solid ^{3}He

RESISTIVE and HYBRID MAGNETS*

FIELD (T), BORE (mm)	POWER (MW)	SUPPORTED RESEARCH
20, 50 20, 200+ 30, 32 33, 32 24.5, 32# 25, 52#+ 45, 32+	8 20 15 19 15 20 20	Magneto-optics—ultra-violet through far infrared Magnetization Specific heat Transport High Pressure NMR in highest fields—low to medium resolution

PULSED MAGNETS**

FIELD (T), BORE (mm)	RISE, DECAY TIME (ms)	SUPPORTED RESEARCH
50, 24 60, 24+ 63, 15 70, 10-14+ 45, 24# 42, 24 60, 32	6, 30 7, 35 9, 60 100, 500 100 ms flat-top and variable pulse shape	Magneto-optics—ultra-violet through near infrared Magnetization Transport High pressure NMR in highest fields—low resolution Quasi-continuous, controlled pulse magnet—expands opportunities for all research conducted in pulsed magnet systems

MAGNETIC RESONANCE SYSTEMS

FREQUENCY	FIELD (T), BORE (mm)	HOMOGENEITY	MEASUREMENTS
1066 MHz*+	25, 52	1 ppm	Solid state NMR
830 MHz*	19.6, 31	100 ppb	Solid state NMR
720 MHz*	16.9, 50	1 ppb	Solution state NMR
600 MHz*	14, 89	1 ppb	MRI and solid state NMR
600 MHz***	14, 50	1 ppb	Solution state NMR MRI/S
500 MHz*	11.75, 50	1 ppb	Solution state NMR
500 MHz***	11.75, 50	1 ppb	Solid and solid state NMR
400 MHz*	9.3, 50	1 ppb	Solution state NMR with high Tc probe
300 MHz*	7, 50	1 ppb	Solution state NMR
300 MHz*	7, 89	1 ppb	Solid state NMR
200 MHz***	4.7, 330	0.1 ppm	MRI/S of animals
125 MHz***	3, 800	0.1 ppm	Whole body MRI/S
Up to 7 THz*	30, 32	100 ppm	ECR
700 GHz*+	25, 52	1 ppm	Multifrequency EMR
470 GHz*	17, 61	3 ppm	Multifrequency EMR
400 GHz*+	14, 88	3 ppm	Transient EMR
9 GHz*			X-band EPR
	25, 52*+	1ppm	ICR
	20, 50*	1000 ppm	ICR
	9.4, 210*	1 ppm	ICR
	7, 150*	10 ppm	ICR
	6, 150*	10 ppm	ICR
	5.6, 90*	10 ppm	ICR
	3, 150*	10 ppm	ICR

MASS SPECTROMETERS*

TYPE OF IONZATION	MASS ANALYZER CONFIGURATION	DETECTION SYSTEMS	MEASUREMENTS	SAMPLE INTRODUCTION
Thermal and Sputtering	E-M-D1-E-D2	D1: 4 Faraday cups after M D2: Daly Ion counting and Faraday cup	Isotope ratios: Th, Hf and Hg	Solids and chemical separates
Thermal	M-D1-E-D2	D1: 7 Faraday cups, 1 electron multiplier D2: Electron multiplier	Isotope ratios: Pb, Sr, Nd, Os	Chemical separates
Thermal-Plasma	M-E-D	D: Electron multiplier	Concentrations and isotope ratios	Solutions

*=Tallahassee E=Energy filter
**=Los Alamos M=Magnetic mass filter
***=Gainesville +=Under development
#=Higher homogeneity magnet

THE NHMFL AT FLORIDA STATE UNIVERSITY, TALLAHASSEE

Continuous Field Facility

The DC facilities in Tallahassee have a unique and extremely powerful infrastructure—a 36 MW DC power supply with ripple and noise approaching 10 ppm and an overload capacity to 40 MW for an hour or 68 MW for several minutes. The complex also has a very low vibration cooling system that is especially important for experiments with very small signals. The Continuous Field Facility also has extensive support capabilities, including a machine shop, an electronics shop, and computer support.

The continuous field magnet systems available or under development (as described in the table) include resistive, superconducting, and hybrid magnets. The world's highest continuous field resistive magnet—33 T in a 32 mm bore—is located in this facility, as well as a 24.5 T, 32 mm bore, high homogeneity magnet that has proven to be an extremely useful experimental tool for magnetic resonance research. A 25 T, 52 mm bore Bitter magnet with 1 ppm homogeneity and stability is being developed for magnetic resonance experiments with funding from the NSF and the Keck Foundation. A very large bore—20 T, 200 mm—magnet will be available in the second quarter of 1998 for superconducting magnet coil tests, ion cyclotron resonance, two-axis sample rotation, long-path magneto optics, very high temperatures, and other experiments that will not fit into the other magnets. The 45 T, 32 mm bore, hybrid magnet is expected to be operational in late 1998. This magnet comprises a 14 T, 610 mm, warm bore, cable-in-conduit, superconducting outsert with a 24 MW, 31 T, resistive insert.

Instrumentation to support the kinds of research listed in the table is available along with people to assist scientists with their experiments. Complete descriptions of the instrumentation are available on the Users pages of the NHMFL web site at *http://www.nhmfl.gov/users*, or by email to *brandt@magnet.fsu.edu*.

Magnetic Resonance Facilities

The NHMFL's Center for Interdisciplinary Magnetic Resonance was established in 1994 to support studies in nuclear magnetic resonance (NMR), magnet resonance imaging (MRI), electron magnetic resonance (EMR), and ion cyclotron resonance (ICR). A unique feature of CIMAR is the large-scale integration of NMR, MRI, EMR, and ICR spectroscopies. Cross-fertilization among these fields is facilitated at the laboratory in several ways through a broad-based external and internal users program.

Although the magnetic resonance program spans all three NHMFL sites, the primary facilities for NMR, EMR, and ICR are housed in Tallahassee. A variety of NMR systems is available, including an 89 mm bore, 600 MHz spectrometer for solids and imaging; a 830 MHz, 31 mm bore magnet for solids, and a 400 MHz system with a superconducting probe for solution NMR.

EMR, which includes electron paramagnetic resonance (EPR) and electron cyclotron resonance (ECR), is conducted in both resistive and superconducting magnets. Highlighting the EMR program are the 700 GHz spectrometer developed with the "Keck" resistive magnet and the 400 GHz transient EMR machine. The 700 GHz instrument is the highest frequency/field machine in the world. The 400 GHz transient machine will allow the study of fast phenomena in the sub nanosecond range, which is of paramount interest in photosynthesis for instance; this instrument will be unique in the world.

The centerpiece of the ICR program is a 9.4 T, 1 ppm, 220 mm warm bore, shielded superconducting Oxford magnet system. This is the highest performance system of its kind in the world, offering users unparalleled opportunities to identify and characterize large molecules including peptides, proteins, oligosaccharides, and nucleic acids. In addition, ICR systems at 11 T and 17 T are under construction.

The NHMFL, in partnership with Intermagnetics General, is developing a 1.1 GHz (25 T) high resolution magnet system for NMR. The first phase of this program includes the design and fabrication of an ultra-wide bore (140 mm cold bore, 110 mm warm bore) high resolution 900 MHz NMR magnet. This system is expected to be completed in early 1999, and it will serve as a platform for the incorporation of a high temperature superconducting central magnet that will provide the additional 4 T needed to achieve the 25 T goal.

Geochemistry Facilities

The mass spectrometry facility includes a better than Class 500 wet chemistry clean laboratory. This lab is used for the separation and purification of all elements that are analyzed by solid source mass spectrometry. In addition, the facility has two vacuum lines used for separation and purification of samples for light stable isotope analysis. The facility has three mass spectrometers providing a unique combination of ionization techniques: sputtering and thermal ionization as well as ionization in a plasma source. The Lamont Isolab, the only one of its kind in the United States, is outfitted with a Daly detection system and 5 faraday cups, has thermal ionization and secondary ionization capability.

The facility includes a fully automated, 7 collector, FinniganMAT 262, mass spectrometer equipped with a retarding potential quadrupole for increased abundance sensitivity and a 13 sample touret. This second mass spectrometer is be used for Sr, Nd, Pb and U isotope ratio analyses by positive thermal ionization and Re and Os by negative ionization, as well most isotope dilution analyses.

The third mass spectrometer is a high resolution inductive coupled plasma mass spectrometer. This instrument represents a new generation of ICP-MS as the mass analyzer is a magnetic sector instead of a conventional quadrupole magnet resulting in a superior mass resolution and transmission. This instrument is used for low level trace element analysis as well as isotope ratio analysis.

Materials Characterization Facility

The resources and facilities of this facility are dedicated to the characterization of materials proposed for use in high field magnets and other cryogenic applications. The facilities provide testing and analysis services to NHMFL magnet design teams as well as industrial and academic researchers.

The laboratory provides precise measurements of electrical resistivity, thermal expansion, and superconductor critical currents. Mechanical properties such as tensile, compressive, fatigue, and shear strength can also be measured. There are three servohydraulic test machines for performing mechanical tests over a range of temperatures (1.8 K to 400 K). Two superconducting magnets can provide background fields of up to 15 T in conjunction with mechanical and electrical tests.

Several examples of the type of materials research projects that have been supported in 1997 are:

- Large scale mechanical and electrical characterization of cable-in-conduit conductors in high magnetic field for the NHMFL Hybrid Magnet.
- Participation in an international cooperative program (VAMAS) to standardize low temperature test methods and analyses.
- Collaboration with General Atomics Inc. and Naval Surface Warfare Center to characterize low temperature mechanical properties of large scale composite struts for Superconducting Mine Countermeasure Systems.
- Collaboration with CEA, Saclay, France to measure thermal and mechanical behavior of aluminum-stabilized composite super-conductors.
- Collaboration with Los Alamos National Laboratory to characterize high cycle fatigue properties of candidate materials for a proposed 30 T neutron scattering magnet.
- Ongoing characterization of high strength, high conductivity, commercial conductors for

resistive magnet and pulse magnets working closely with industrial partners Brush-Wellman and Supercon.

- Electrical and mechanical properties characterization of composite conductors such as stainless steel-jacketed copper for pulse magnet applications.

The NHMFL at Los Alamos National Laboratory

Pulsed Field Facility

LANL is home to the NHMFL's Pulsed Field Facility because of that laboratory's unique facilities for the production of pulsed electrical power and the dedicated sites for flux compression experiments. The Pulsed Field Facility is supported by a capacitor bank of 1.2 MJ and a motor generator capable of delivering an energy pulse of 600 MJ. The motor generator can be upgraded to 2000 MJ with the addition of a flywheel and power supply modules.

A variety of pulsed magnet systems are available at NHMFL-Los Alamos including 50 T and 63 T capacitive-driven magnets with 24 mm and 15 mm bores, respectively. All of these systems are equipped with an assortment of dilution refrigerators, He-3, and variable temperature inserts, and instrumentation that supports transport, magnetization, high pressure, and optics studies. Four magnet stations, collaborative opportunities, and user support are available.

A 60 T, 32 mm bore, quasi-continuous magnet was commissioned in 1997 and set a new world record—60 T—for this type of magnet. Besides being the most powerful of its class in the world, this magnet is also the first of its kind in the United States. It promises to be a significant new research tool. User experiments began in late 1997, and requests for magnet time from industrial and university users from around the world have been high.

In addition to systems currently available, a non-destructive 100 T (24 mm bore), 20 ms to 50 ms pulsed magnet is being developed by the NHMFL and LANL as a jointly-funded effort between the U.S. Department of Energy and the National Science Foundation.

A 19.5 T superconducting magnet with 52 mm bore is also available. This magnet is equipped with a variety of probes, including: dilution refrigerator, variable temperature inserts, and high temperature insert allowing experiments from 20 mK to 500 K. This magnet not only serves as staging magnet for calibration purpose for pulse fields experiments but also as an excellent tool to measure magnetotransport, heat capacity, thermal-expansion and magnetostriction in a wide temperature range.

Flux Compression Experimental Areas

Academic and industrial researchers may access the unique magnetic flux compression experimental areas at LANL through a cooperative arrangement with the NHMFL. The flux compression technique employs chemical explosives to produce magnetic fields of 100 to 700 T for microsecond durations in 11 to 16 mm bores. For a limited number of experiments, Russian MC-1 flux compression generators are available producing fields up to 1000 T in an 8 mm bore. In all of these systems temperatures down to 2.3 K can be attained for liquid helium flow through cryostats and to 1.8 K for pumped vacuum insulated cryostats. Experimental techniques have been developed to reliably acquire electrical transport, de Haas van Alphen, Faraday rotation, optical emission and absorption in the fast risetime environment. A wide range of electrical, spectroscopic, and photographic instruments are available for high speed data recording.

Support instrumentation, information and proposal forms are available on the Users pages of the NHMFL-Los Alamos web site at: *http://www.mst.lanl.gov/nhmfl/welcome.html*, or by email to *lacerda@lanl.gov*.

The NHMFL at the University of Florida, Gainesville

Ultra-High B/T Facility

The NHMFL commissioned an ultra-high magnetic field and low temperature facility in 1997, known as the Ultra-High B/T Facility. This facility provides researchers with the opportunity for studying phenomena that require simultaneous high magnetic fields and low temperatures. Current facilities provide 15.5 T with homogeneity of 50 ppm over 10 mm DSV and temperatures as low as 0.5 mK with a cooling capacity of the order of 10 nW. Values of the ratio of magnetic field to temperature with B/T up to 4 x 10^4 T/K are available to users. Many new phenomena that require the establishment of high spin polarizations or high magnetizations, including nuclear magnetism, magnetokinetics, polarized quantum fluids, quantum-confined structures, and non-Fermi liquids, may be explored in this research facility. Some of the experiments planned with users in the near future include quantum Hall effect studies; determination of the upper critical fields for ordered phases in solid ^{3}He; and transport measurements for polarized dilute ^{3}He-^{4}He liquid mixtures.

Nanofabrication Facility

Facilities are also available at UF for the fabrication and characterization of nanostructures at a new Nanofabrication Facility being operated in conjunction with UF's Major Analytical and Instrumentation Center (MAIC). The full capabilities of MAIC include:

- Atomic force microscope(AFM/STM)
- High-temperature x-ray diffractometer (XRD)
- Scanning electron microscope (SEM)
- Scanning transmission electron microscope (STEM)
- Electron microprobe (EMP)
- X-ray photoelectron spectrometers (XPS) (one dedicated to polymers and the other to high vacuum samples)
- Scanning Auger electron spectroscopy (AES)
- Energy dispersive x-ray spectroscopy (EDS)
- Electron energy loss spectroscopy (EELS)
- Secondary-ion mass spectrometer (SIMS)
- Ion backscattering spectroscopy (IBS)
- Ion scattering spectroscopy (ISS)
- Field ion microscopy (FIM)
- Digital scanning electron microscope
- High resolution transmission electron microscope
- High resolution x-ray diffractometer
- High vacuum scanning probe microscope
- Electron microscopy and microanalysis
- Electron beam lithography
- Particle induced x-ray emission
- Laser-plasma x-ray microscopy.

Magnetic Resonance Imaging Spectroscopy

NHMFL user facilities for high-field magnetic resonance imaging spectroscopy (MRI/S) are available in Gainesville. From the comprehensive list shown in the table, users might be particularly interested in the 125 MHz, 3 T, 0.1 ppm, 800 mm warm bore MRI/S magnet system, which has very fast imaging capabilities and is available for collaboration on functional, whole-body, imaging studies.

UF Brain Institute

The NHMFL has established strong ties with the UF Center for Structural Biology and the UF College of Medicine, and will consolidate its MRI efforts at the UF Brain Institute, scheduled to open in 1998. For more information, see *http://www.ufbi.ufl.edu/.*

THE NHMFL PROPOSAL REVIEW PROCESS

As a national user laboratory, members of the worldwide science and engineering communities can access these facilities, generally without cost, through a peer-reviewed proposal process. Contact one of the people listed below for further information.

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